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INSPECTION GOGGLE FOR CHECKING VISIBLE SPECTRAL QUALITY OF LIGHTING FOR DARK ADAPTATION

by
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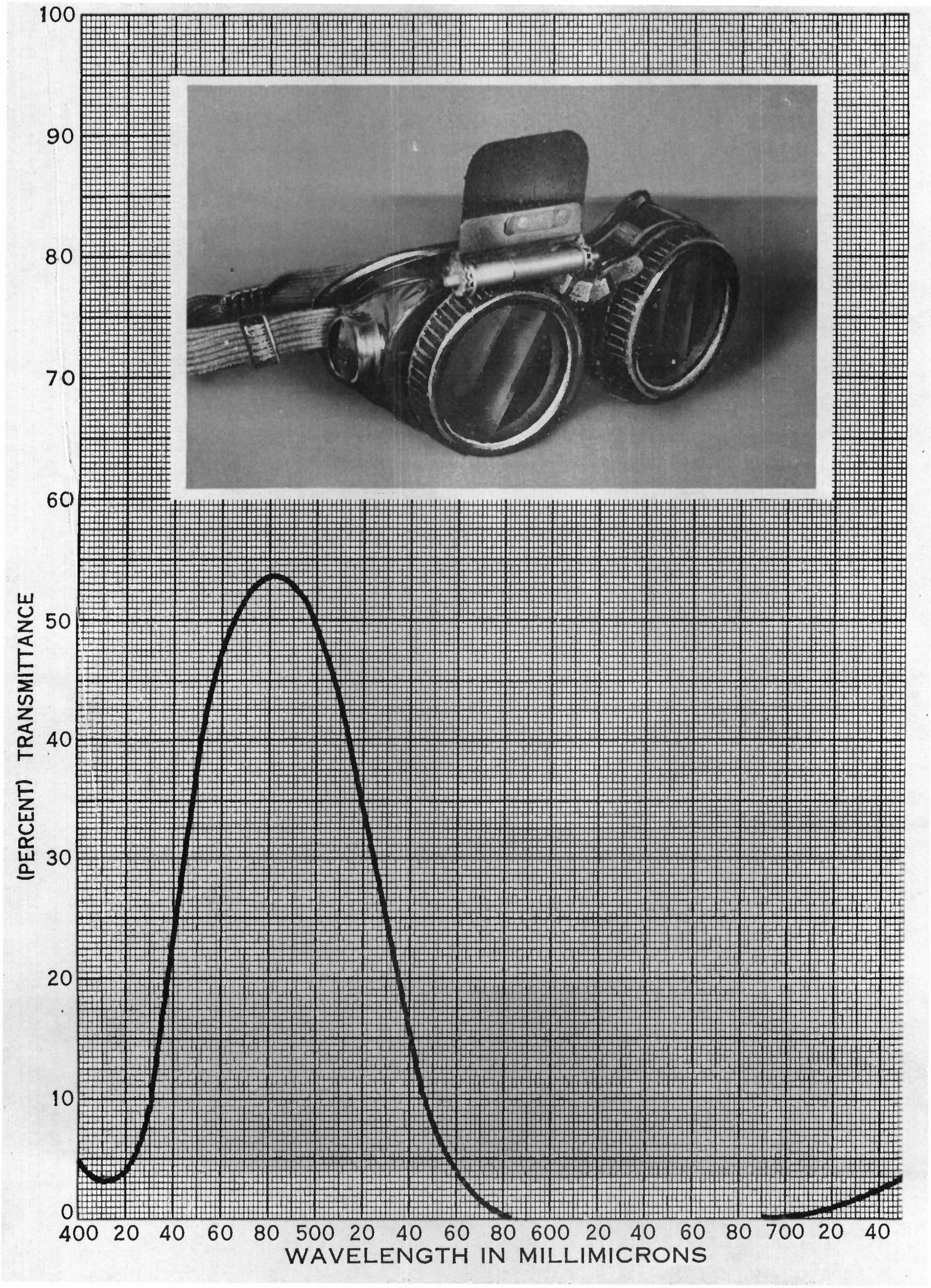

(PERCENT) TRANSMITTANCE
100
90
80
70
60
50
40
30
20
10
0
400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700 20 40
WAVELENGTH IN MILLIMICRONS

INSPECTION GOGGLE FOR CHECKING VISIBLE SPECTRAL QUALITY OF LIGHTING FOR DARK ADAPTATION

by

Dean Farnsworth

Reference may be made to this report as follows: Farnsworth, D., "Inspection goggle for checking visible spectral quality of lighting for dark adaptation", MRL Report No. 170, Vol. 10, pp. 1 - 17, 1951.

Report No. 1 on BuMed NM 003 041.40
Laboratory Instruments and Devices

OPERATIONAL APPLICATION

The efficacy of red lighting for promoting dark adaptation lies not in its red appearance but in the absence of shorter wave radiation. Conformity to Naval specification can be determined by spectrophotometric analysis and calculation but this method is not readily available to the operating forces or to manufacturers of equipment.

A simple inspection goggle is described which will, in general, indicate whether or not red-lighted units and installations are acceptable or not acceptable. It is made by inserting Eastman No. 44A Wratten filters cemented in 1 15/16" discs of "B" glass in a standard industrial type goggle. The goggles are worn for about two minutes before making observations. All illumination which appears red through the filters is within the accepted range of spectral light which permits rapid subsequent dark adaptation. If any light appears yellow, orange, green, blue, purple or whitish it indicates the emission of radiation which is detrimental to dark adaptation to some degree. All information necessary for making and using the goggles is given on pages 8 and 9.

It should be borne in mind that this device does not take into consideration the brightness of the light. A combination of properly filtered red light and minimum brightness levels are necessary conditions for optimum preadaptation for rapid subsequent dark adaptation. Regardless of the spectral quality, red lighting should be kept at the minimum brightness which is compatible with adequate execution of the task.

ABSTRACT

An inspection goggle is described with which a visual check can be made by an eye of normal color vision of the spectral composition of red light to determine its conformance to Naval specifications for dark adaptation. Observed results on sample glasses are compared with calculated results.

INSPECTION GOGGLE FOR CHECKING VISIBLE SPECTRAL QUALITY OF LIGHTING FOR DARK ADAPTATION

Whenever men must continue working under some illumination but also continue in a state of partial adaptation for night vision, it has been found necessary to use red illumination exclusively[1]. Wavelengths of about 600 millimicrons and above have been found most favorable to preadaptation and wavelengths below 600 mu inhibit preadaptation with increasingly detrimental effects down to 400 mu and into the invisible ultraviolet. It is customary to secure red illumination by using filters in a variety of ways: in goggles, over instrument panels, as domes over incandescent lamps, as jewels in front of indicator lights.

An empirical formula for the specification of red filters was derived by Webster and Lee[2] from a series of experiments in 1942. In brief, they concluded that (1) there must be no appreciable transmission in the wavelength range 360 to 580 mu, (2) the sum of the spectral transmission in 10 mu steps multiplied by "rod visibility factors" is not to exceed 11.0, and (3) when multiplied by "cone visibility factors" the sum is to be greater than 120.0. This report was made the basis of U.S. Naval specifications for procurement of red filters[3].

There has been frequent need since 1942 for a simple method of checking the "dark adaptation safety" of installations in the cockpits of aircraft, submarine conning towers, gondolas of dirigibles and combat information centers on surface vessels. Formulae based on psychophysical data are valuable for setting standards and for writing specifications but do not provide a feasible method for checking assembled instruments and installations. The problem is difficult because of the following reasons and complications:

(1) Since the eye is an unanalytical instrument, visual observation alone cannot determine whether or not a red filter is also transmitting between 400 and 600 mu.

(2) Even though the filters in indicator panels meet specifications, the intention may be defeated by stray light which "leaks" out of cabinets and around fittings.

(3) Luminous paints and ultraviolet sources irradiating fluorescent materials result in complex effects which are difficult to foretell before final assembly.

(4) The installation of compartment fixtures or general illumination (including daylight and incandescent leaks from adjacent areas) may be at fault and these can be tested only on location.

(5) Instruments, control panels, dials and illuminating equipment are usually furnished by a number of manufacturers and are prefabricated at different plants. Therefore, many kinds of materials and light sources may be installed before there is opportunity for checking them. It is usually delaying, inconvenient, or impossible to remove these filters and light sources and send them to a laboratory for spectrophotometric examination and calculation. Even if it were feasible to specify or individually analyze all the red filters in an installation, several things would remain unchecked - stray light, compartment lights, replacements and the effects of deterioration. On the other hand, it is not practical to take a laboratory spectrophotometer into a compartment or cockpit to examine each source separately.

Therefore, it was evident that a testing method was needed which (1) could be used in situ, (2) would survey the entire installation (3) preferably from operators' eye positions, and (4) would be simple to use - essentially fool-proof in the hands of untrained people and (5) it should be a quick method which would discover serious shortcomings of the installation but need not be of an order of accuracy comparable to spectrophotometry.

DESCRIPTION OF INSPECTION FILTERS

A system was devised by this Laboratory for checking "rigged for red" compartments in submarines in 1943. At the request of Admiral Rosendahl in 1944, it was adapted to testing the lighting in dirigibles designed to provide dark adaptation for the crews while on night search for enemy submarines. The method has since been used by manufacturers, designers, contract agencies and inspectors in the Armed Services. The following history incorporates changes and simplifications in technique that have been made as a result of those experiences.

The first test filter was selected to transmit light from the violet to the orange and cut off sharply beyond 590 mu. It was found to be most effective when installed in a goggle since this permitted a constant state of adaptation which reduced the disorienting effects of variable brightness contrasts. The first specimens (designated "Sample #1104") were limited in usefulness because the eyes became so sensitive to wavelengths from 400 to 500 mu after a period of dark adaptation that a really negligible amount of short wave energy appeared very bright. Only experienced observers were able to distinguish between negligible and significant amounts of stray energies. One solution was the use of a filter which transmitted a small amount of long wavelength energy thus providing a constant red "load", whether at photopic or scotopic levels of adaptation, which would balance out inconsequential amounts of short wavelengths. Such a constant "load" is available anywhere in the region above 650 mu where the rods and cones are about equally sensitive to radiation. Various filters were tried which had secondary transmittances beginning at from 650 to 800 mu, of which the 690 mu proved to be most successful.

Fortunately, a filter of the required characteristics was available from Eastman stock gelatins. A sample of Wratten No. 44A gave reasonably high transmittance up to about 580 where it cut off sharply and thereafter transmitted only at 690 and beyond; the light flux of wavelength greater than 690 mu transmitted by the filter is about 0.001 that of a beam of incandescent light on it when assessed by cone vision. Transmittance data obtained on two samples of 44A approximated the data given in the Wratten Filter Catalog in essential respects (Figure 1). The curves are so close to the ideal that it is unnecessary to try to develop a filter made to more exact specification.

If some orange, green or violet is transmitted by the light under test it will combine with the red light to make an orangish, magenta or paler red which may not be noticeably different from a long wavelength red. This trace of short wave color is not likely to be of importance but for occasions when such exactness is required the light of suspected impure red can be viewed through a standard red plastic which is attached to the goggle. If the addition of the red plastic causes a perceptible difference in color it can be assumed that the sample does not quite meet standard specifications.

The plastic can be unsnapped from the goggle and used as a demonstration of the properties of a standard red filter when examined by the test goggles. It is not necessary, of course, for the standard red plastic to be attached to the goggles, but attachment is convenient and will prevent loss, misplacement or confusion with non-standard samples.

Limitations. The limitations of this inspection filter should be noted: (1) it will not detect the presence of ultraviolet (invisible) energy, (2) it is not a measure of brightness or the level of illumination from a given source, (3) it does not

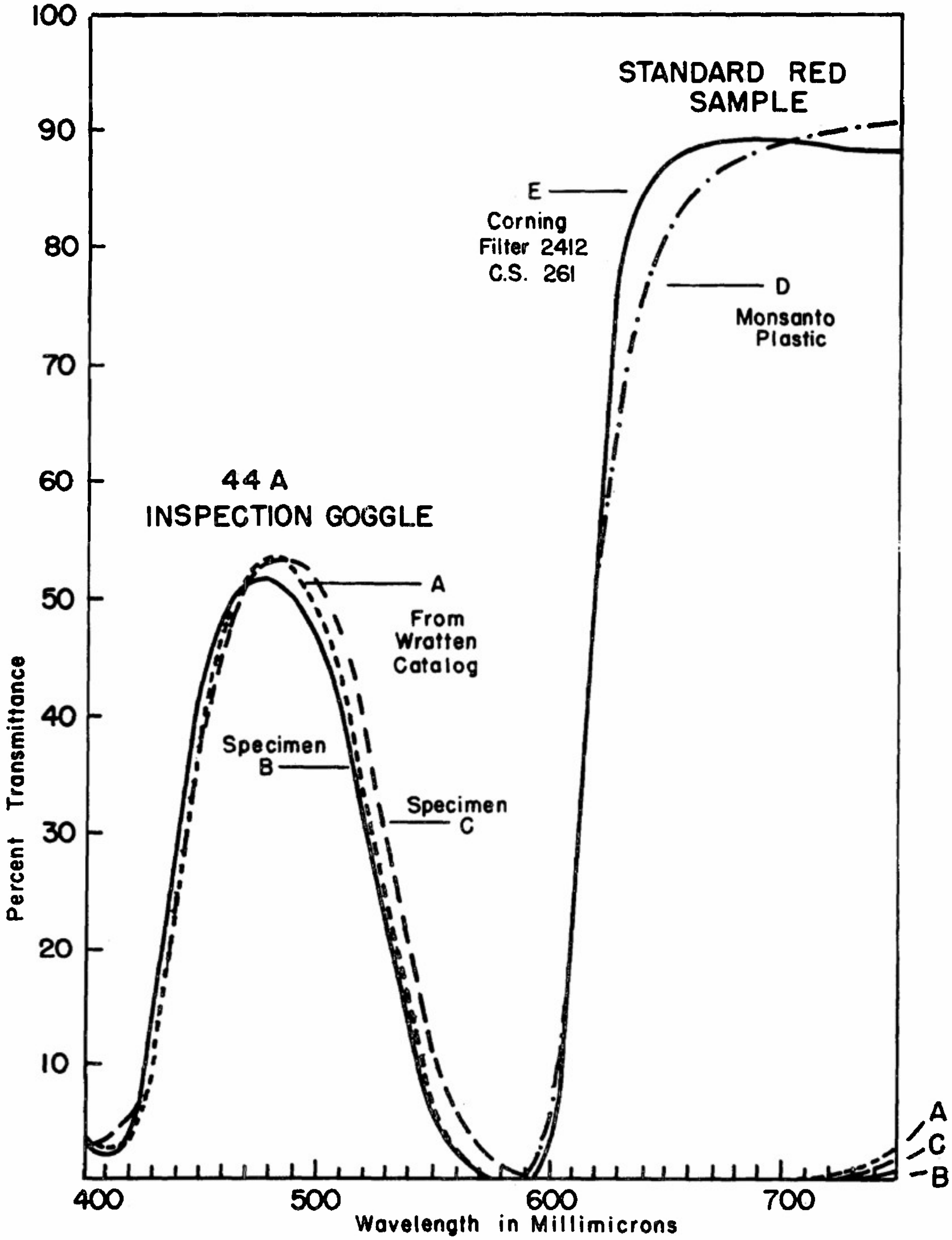

Figure 1

Spectral transmittance of filters in Inspection Goggle:

A. Wratten 44A, from table in Eastman Filter Catalog
B. Wratten 44A, cemented in B glass, received May 1945
C. Wratten 44A, cemented in B glass, received Feb 1951
D. Red plastic used for flipper or standard sample, 1946
E. Corning sharp cut-off glass, Color spec. 261, Filter 2412. Equally steep curves not now available in plastic.

give a substitute for calculation when borderline decisions must be made as to whether a filter meets a precise specification, (4) the filter is related to one particular specification; it was chosen only to pass filters which conform with, and to reveal those which are grossly incompatible with, that specification.

DESCRIPTION GOGGLE

A common cup-type safety goggle is used to hold the filters. The model illustrated in the frontispiece is a Willson Eyecup Chipper, Stock No. 37-G-3450, Navy specifications 37-G-17. The cap of each goggle is designed to hold a circular lens of 50 millimeters (1 15/16 inches) in diameter. The Willson flash goggle, F350L, Navy stock No. 37-G-3563, carried at the Newport Supply Depot, is lighter and more comfortable but the substitution of the filters requires more care. Wratten filters No. 44A cemented in 50 millimeter circles of "B" glass are substituted for the safety glass discs with which the eye-cups are normally furnished. The cemented filters are obtainable from the Eastman Kodak Company, Rochester, New York. A 1 1/4" x 2 " sheet of standard red plastic is hinged at the top of the frame so that it can be turned down to cover one-half the field of the right eye-cup. The red plastic is Nitron sheet stock, Color #22021-TVA-6, manufactured by the Monsanto Chemical Company. Transmissions of specimen filters are shown in Figure 1.

USE OF THE GOGGLE

The observer must have normal color vision.

The goggle should be worn for about two minutes before making observations. The light, instrument or section of the compartment should then be observed, item by item. All illumination which is within the accepted range for promoting dark adaptation will appear red. If any lights appear yellow, orange, green, blue, purple or whitish it indicates the emission of short wave light which is detrimental to dark adaptation to some degree.

If the observer is in doubt whether the light is orangish rather than reddish, or pinkish or magenta rather than reddish, the red flipper should be lowered to cover half of the field of the right eyecup and the head moved up and down so as to bring the tested light alternately into each half of the field. The presence of short wavelengths in the light is indicated if there is a difference in color when observed in these two ways.

To test the transmission of a glass or plastic filter, the sample filter should be held in front of an incandescent light. With the test goggles on and the red flipper down, the sample filter should appear the same color through the red flipper as it does through the other half of the right eyecup. Incandescent light should always be used in testing (unless the filter will be used in front of fluorescents) because fluorescents are deficient in red rays and may give a misleading indication.

FIELD OBSERVATIONS

Analyses have been made of some thirty types of colored lamps and filters taken from military equipment. Lamps examined included "naturals" (colored glass), outside coated and dipped. Colored media have included glass, acrylics, methacrylates, acetates, gelatins and various poured and formed jewels in glass and plastics. The most notorious offenders were the common flashed ruby glass, coated and dipped indicator lamps and the bright orange-red jewels commonly used for off-and-on signals. Materials that met standard specifications were found in stock colors in Corning Signal Glass, Rohm & Haas Plexiglas and Monsanto sheet plastic, and are no doubt available from other manufacturers' lines. The chief conclusions that can be drawn from the survey is that unaided visual observation is no clue as to whether the filters, lamps and colored media meet Navy specifications.

The goggles have been used to inspect complete installations in submarine compartments, lighter-than-air craft, combat information centers, aircraft cockpits, and plane-spotting towers. In addition to the poor filters mentioned above, two sources of extraneous light were frequently discovered, stray light from radio equipment and stray white light entering from adjacent compartments, from below or above decks or through incompletely masked windows or entryways.

VALIDATION OF METHOD

The efficacy of this system has been proved by examining a variety of red-appearing filters of which the transmissions were accurately known. Three pair are chosen for demonstration. The transmissions are shown in Figures 2, 3 and 4.

Glasses A and B appear almost identical to the eye even though their transmittance curves as seen in Figure 2 are high-

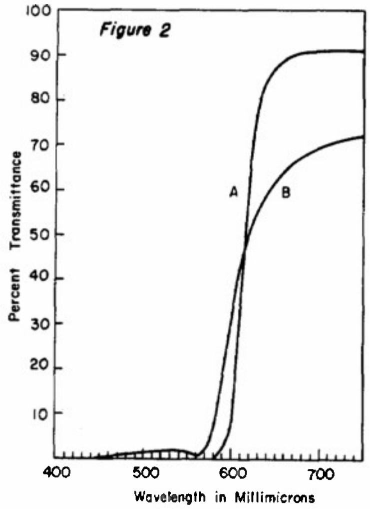

Figure 2

Spectral transmittance of red filter samples A and B

ly dissimilar. When viewed through the test goggles, A appears pure red and B appears bright green - which is a true indication of the unacceptability of B. This appraisal may be compared with the results by the Webster-Lee formula:

	Sum R x T must not exceed 11.0	Sum C x T must exceed 120.0
Filter A	11.8	146.6
Filter B	18.3	156.2

The inspection goggle is seen to be slightly more lenient than the formula because it accepts Filter A which is just over the criteria for the Sum R x T, but concurs with the formulae in decisively rejecting Filter B.

More subtle distinctions are possible with the goggles. Figure 3 shows a red plastic, Filter C, with a fairly sharp cut-

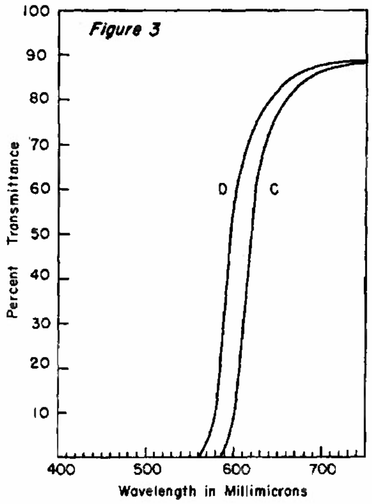

Figure 3

Spectral transmittance of red filter samples C and D

off which meets specifications, and another plastic, Filter D, with a similar curve whose transmission extends further into the shorter wavelengths. They appear of very much the same color to the unaided eye, one being lighter than the other. When observed through the test goggle, Filter C appears pure red and shows substantially no change through the flipper. Filter D appears orangish red and loses its orange quality when observed through the flipper. Therefore, by the use of the test goggle, Filter C is accepted as meeting specifications and D rejected. Similar results are reached by calculation with the Webster-Lee formula:

	Sum R x T must not exceed 11.0	Sum C x T must exceed 120.0
Filter C	10.9	131.7
Filter D	34.1	249.8

The formula barely passes C and definitely rejects D; the test goggle passes C and barely rejects D.

The goggle inspection method is again shown to be less restrictive than the limits set in the Webster-Lee formula. This may be a desirable feature in a test for gross examination since it cannot raise false alarms by rejecting a surely acceptable glass. It might be undesirable to select a more restrictive test filter because of the manufacturing variation in gelatins.

The third case is especially instructive. Not only do Filter E and Filter F appear similar to the eye but the essential differences in efficacy are not immediately obvious even from inspection of the spectrophotometric curves in Figure 4.

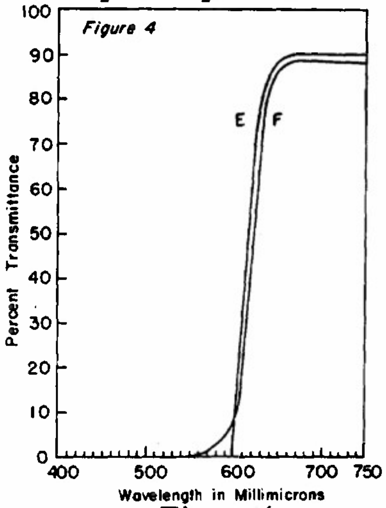

Figure 4

Spectral Transmission of red filter samples E and F

Yet, through the test goggles Filter E appears pure red and F appears yellowish. Therefore, Filter E is acceptable and F is not, and this appraisal is exactly confirmed by the Webster-Lee formula:

	Sum R x T must not exceed 11.0	Sum C x T must exceed 120.0
Filter E	9.3	123.5
Filter F	12.0	111.2

(Work sheets for these two filters are given on the pages following "Notes and References").

The above result is surprising because the little bend at the base of the F curve appears too small to be consequential unless one considers the psychophysical factors which apply. These are presented graphically in Figure 5a, b, c and d. Figure 5a presents the data which is involved - the transmission curves for the two Filters E and F, the curve for the standard I.C.I. luminosity function for photopic vision(4) and a curve for the scotopic function from Weaver(5).

The first factor to be noted is that increments of stimulus do not produce corresponding increments of sensation in a linear way but rather resemble a logarithmic relationship. Therefore, the transmission curves for Filters E and F in 5a have been plotted on a logarithmic scale in 5b.

It is next noted that photopic (cone) vision is variably responsive to different physical energies from 400 to 700 mu. This is represented by the photopic curve in 5a; these data are applied to the transmission curves E and F and plotted on a logarithmic scale in 5c. Here it appears that the two filters are of a similar order of brightness for cone, or photopic, visual functions as indicated by the areas under the curves.

However, we are not only interested in the transmission of these filters for ordinary purposes - reading, writing and dial illumination - but in the relative effect they will have on subsequent dark adaptation which is a scotopic, or rod, function. Applying the scotopic factors given in 5a to the curves E and F we plot the data in 5d. This shows conclusively that Filter F, because of its relatively high brightness to rods, will have a greater deterrent effect on dark adaptation than will Filter E.

The advantage of the proposed inspection goggle is that it by-passes such calculations and, by the aid of the normal eye, reports directly the prospective effect of filters on subsequent dark adaptation.

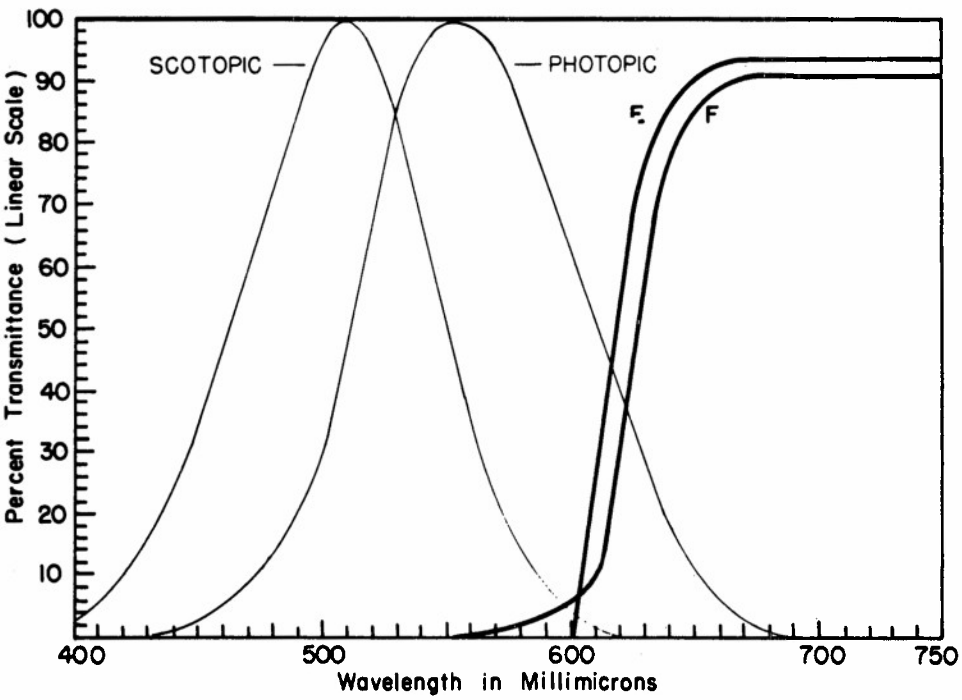

Fig. 5A

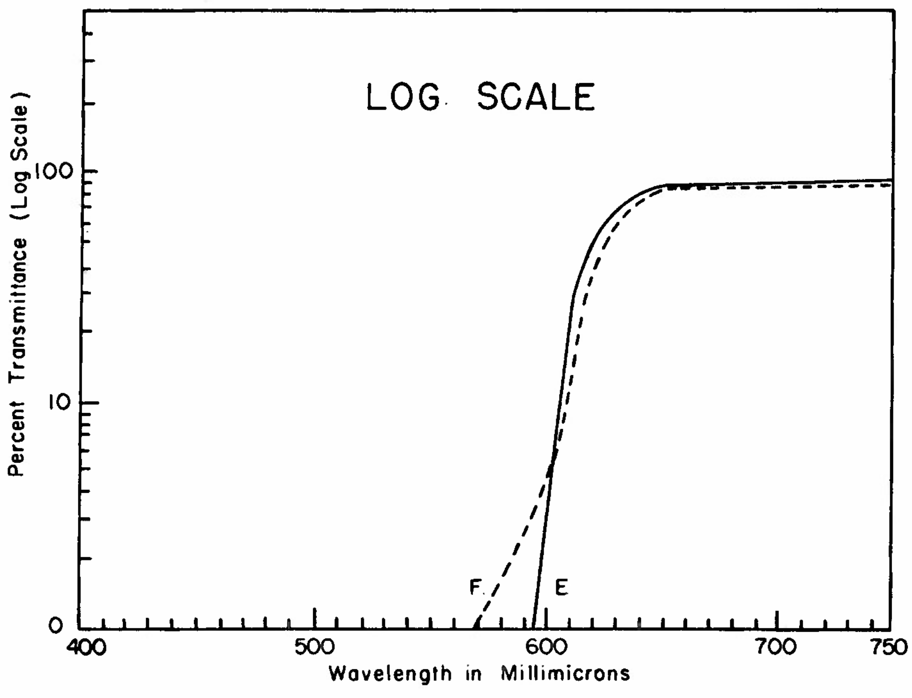

Fig. 5B

Figure 5

Graphic application of psychophysical factors to trans-mission curves of two filters (see text).

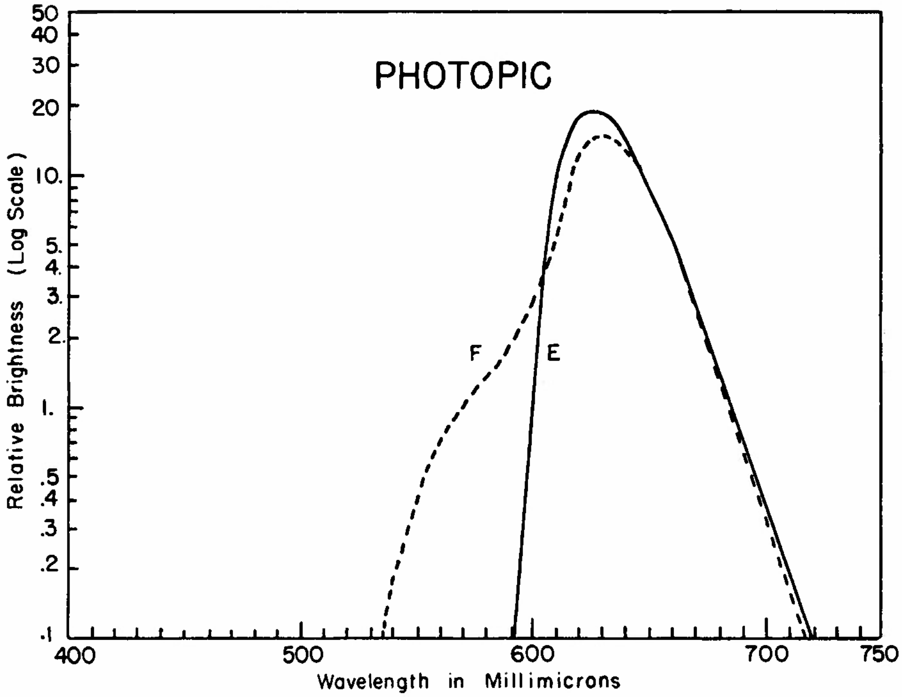
PHOTOPIC
Relative Brightness (Log Scale)
50
40
30
20
10.
5.
4.
3.
2.
1.
.5
.4
.3
.2
.1
F
E
400
500
600
700
750
Wavelength in Millimicrons

Fig. 5C

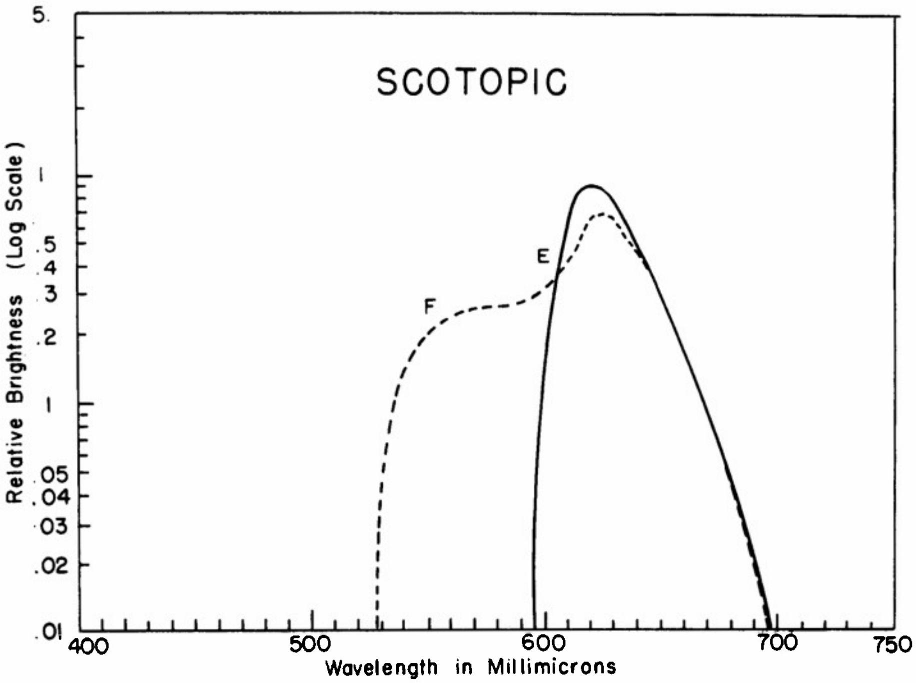
SCOTOPIC
Relative Brightness (Log Scale)
5.
1
.5
.4
.3
.2
.1
.05
.04
.03
.02
.01
F
E
400
500
600
700
750
Wavelength in Millimicrons

Fig. 5D

SUMMARY

A goggle has been designed incorporating filters which permit the visual detection of the presence of short wave (400-580 mu) visible energy in light sources or from illuminated surfaces. Lights which pass inspection by this device conform closely to Navy specifications for filters for dark adaptation and lights which do not pass inspection definitely exceed the standard limits.

Detailed description is given so that any laboratory or contractor can make up its own goggles.

The test goggles are intended to be used for gross inspection of installations of equipment and should not be substituted for spectrophotometric measurement in critical applications.

NOTES AND REFERENCES

1. The earliest reference to the use of red illumination to promote dark adaptation appears to be in a study by Ives and Shilling in 1941 which incorporates a letter from Dr. Walter R. Miles concerning the use of red goggles in his studies of dark adaptation. Dr. Miles made specific proposals for the use of red filters in connection with submarine operations to "permit the subject to use the cones for purposes of reading while the rods are dark adapting".

W.C. Ives and C.S. Shilling, "Night adaptation after exposure to various colored lights". U.S. Navy, Submarine Base, New London, Conn., Medical Research Laboratory, November 13, 1941.

An extensive bibliography with summaries of subsequent work will be found in

William Berry, "Review of wartime studies of dark adaptation, night vision tests and related topics". The Armed Forces-NRC Vision Committee, Published by the Secretariat, Ann Arbor, Michigan, December 1, 1949.

2. A.P. Webster, and R.H. Lee, "Report on the influence of red and white preadapting lights on the course of dark adaptation for various colors of test fields and tests of specific goggles submitted by the Medical Research Section, Bureau of Aeronautics". N.R.C. Report No. 46, March 25, 1942.

Since the above report is not generally available, sample work sheets are shown on the following pages. The two which are reproduced are filled out for the filters E and F discussed in the text of this report.

The critical values given by Webster and Lee are a special application to goggle filters of a computational method first described by Kohlrausch.

A. Kohlrausch, "Untersuchungen mit farbigen Schwellenpruflichtern uber den Dunkeladaptationsverlauf des normalen Auges", Arch. ges. Physiol., 1922, 195, 113-117.

3. CNO. ltr Op 23(2B/1C)(SC)P2/564, Serial 0303423 Subj: Dark Adaptation, 17 March 1942.

4. A.C. Hardy, Handbook of Colorimetry, (Technology Press, Cambridge, Massachusetts, 1936).

5. K.S. Weaver, "A provisional standard observer for low level photometry", J.Opt.Soc.Am. 39, 278 (1949).

Filter No. E..   Date. 6 Feb. 1951..
mss

Wave-length mu	% trans-mittance "T"	Rod Factors "R"	R x T	Cone Factors "C"	C x T
500		4.0		1.0	
510		4.0		1.0	
520		3.9		1.0	
530		3.6		1.0	
540		3.0		1.0	
550		2.0		1.0	
560		1.3		1.0	
570		.7		1.0	
580		.3475		0.9293	
590		.2147		.8684	
600	2.5	.1288	.322	.7718	1.929
610	18.0	.0736	1.325	.6550	11.790
620	48.0	.0429	2.059	.5262	25.258
630	71.0	.0261	1.853	.3871	27.484
640	81.0	.0159	1.288	.2695	21.829
650	87.0	.0100	.870	.1732	15.068
660	89.0	.0067	.596	.1036	9.220
670	90.0	.0044	.396	.0568	5.112
680	91.0	.0028	.255	.0315	2.867
690	91.0	.0018	.164	.0158	1.438
700	91.0	.0011	.100	.0082	.746
710	91.0	.0007	.064	.0044	.400
720	91.0	.0005	.045	.0023	.209
730	91.0	.---		.0012	.109
740	91.0	.---		.0006	.055
750		.---		.0003	
760		.---		.0001	

Sum R x T = 9.337   Sum C x T = 123.514
Must not exceed 11.0   Must exceed 120.0

There must be no appreciable transmission in the wavelength range 360 to 580 mu.

Factors from 500 to 570 mu are extrapolated from author's figures

A.P. Webster and R.H. Lee, "Reports on the influences of red and white preadaptating lights on the course of dark adaptation for various colors of test fields and tests of specific goggles submitted by the Medical Research Section, Bureau of Aeronautics". NRC Report No. 46, 25 Mar 1942.

Medical Research Laboratory
U.S.N. Submarine Base
New London, Connecticut

Filter No. F.. Date. 6 Feb. 1951..
mss

Wave-length mu	% transmittance "T"	Rod Factors "R"	R x T	Cone Factors "C"	C x T
500		4.0		1.0	
510		4.0		1.0	
520		3.9		1.0	
530		3.6		1.0	
540	.2	3.0	.600	1.0	.200
550	.4	2.0	.800	1.0	.400
560	.7	1.3	.910	1.0	.700
570	1.0	.7	.700	1.0	1.000
580	1.6	.3475	.556	0.9293	1.487
590	2.5	.2147	.537	.8684	2.171
600	4.8	.1288	.618	.7718	3.705
610	10.0	.0736	.736	.6550	6.550
620	33.5	.0429	1.437	.5262	17.628
630	58.0	.0261	1.514	.3871	22.452
640	76.5	.0159	1.216	.2695	20.617
650	84.0	.0100	.840	.1732	14.549
660	87.3	.0067	.585	.1036	9.044
670	88.5	.0044	.389	.0568	5.027
680	88.5	.0028	.248	.0315	2.788
690	88.5	.0018	.159	.0158	1.398
700	88.5	.0011	.097	.0082	.726
710	88.4	.0007	.062	.0044	.389
720	88.2	.0005	.044	.0023	.203
730	88.0	.---		.0012	.106
740	87.9	.---		.0006	.053
750	87.7	.---		.0003	.026
760		.---		.0001	

Sum R x T = 12.048   Sum C x T = 111.219
Must not exceed 11.0   Must exceed 120.0

There must be no appreciable transmission in the wavelength range 360 to 580 mu.

Factors from 500 to 570 mu are extrapolated from author's figures

A.P. Webster and R.H. Lee, "Reports on the influences of red and white preadaptating lights on the course of dark adaptation for various colors of test fields and tests of specific goggles submitted by the Medical Research Section, Bureau of Aeronautics". NRC Report No. 46, 25 Mar 1942.

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